Applying Command-and-Control Measures of Effectiveness to the Eagle Combat Simulation Model

Captain George F. Stone III
Cadet Omar J. Jones IV

A TECHNICAL REPORT
OF THE
OPERATIONS RESEARCH CENTER
UNITED STATES MILITARY ACADEMY

Directed by
Major James E. Armstrong, Jr., Ph.D.
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IN COMBAT MODELING, THERE WILL ALWAYS BE A NEED TO QUANTIFY MEASURES OF EFFECTIVENESS (MOE) FOR COMBAT SYSTEMS. HOWEVER, THOSE MOE WHICH ASSESS COMMAND-AND-CONTROL ON THE BATTLE ARE BECOMING EQUALLY IMPORTANT. THIS PAPER PRESENTS TWO APPLICATIONS OF A METHODOLOGY WHICH DEFINES MOE IN TERMS OF AIRLAND BATTLE OPERATIONS DOCTRINE.

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Acknowledgements

Mr. Kent Pickett and Ms. Annette Ratzenberger at the Operations Analysis Center of TRADOC Analysis Command (TRAC) assisted greatly in our achieving a viable and rewarding summer research experience. The entire Eagle Division at the Operations Analysis Center in TRAC was always ready to teach and discuss Eagle's capabilities and procedures. LTC John Ogren and LTC Robert Alexander provided knowledge, guidance and data for measuring command-and-control in Eagle. CPT Bob Short at TRAC shared his insights for developing the C2 application. Thanks to TRAC's assistance and the Military Academy's support for academic enrichment opportunities, combat modeling research can and will enhance future leader development.

Vitae

Captain George Stone was born in Norwalk, Connecticut in 1955. He graduated from the United States Military Academy in 1980. He has served in a variety of field artillery assignments, including two tours as a battery commander. CPT Stone earned his M.S. in Industrial Engineering at Texas A&M University. As an instructor and Assistant Professor in the Department of Systems Engineering at USMA, he has taught courses in Production Operations, Advanced Operations Research, Combat Modeling and Systems Engineering Design.

Cadet Omar Jones was born in Baltimore, Maryland in 1970. He entered the United States Military Academy in 1988 and will graduate in May 1992. Cadet Jones is pursuing a major in Operations Research, co-sponsored by the Departments of Systems Engineering and Mathematical Sciences. Recognized for outstanding leadership potential, Cadet Jones leads the corps of cadets as the Brigade Commander and First Captain.

Executive Summary

In combat modeling, there will always be a need to quantify Measures of Effectiveness (MOE) for combat systems . However, those MOE which assess command-and-control on the battle are becoming equally important. This paper presents two applications of a methodology which defines MOE in terms of Airland Battle operations doctrine.

Initial research efforts apply data from a command -and-control (C2) simulation model, the Eagle Combat Simulation, in order to investigate the effects of C2 parameters in Corps / Division-level battles.

The results of the study reveal that a method for linking C2 MOE with a combat model is relatively simple and very promising for future modeling of command-and-control functions.

Introduction.

One of the most difficult features of any study is finding measures to describe the performance of a force structure, individual unit or combat system. Qualitative measures relating to command-and-control of forces, units or combat systems are harder to capture. This paper proposes an application of a recently-proposed methodology which defined command-and-control measures of effectiveness based on the tenets of AirLand Operations from Field Manual 100-5, Operations.[1] "How to" principles for command-and-control of military forces on the battlefield are prescribed in FM 100-5. Consequently, the measures which assess command-and-control correlate with characteristics outlined in AirLand Operations doctrine. The application for this paper focuses on using data from the Eagle Combat Simulation to relate MOE-formatted characteristics of AirLand Operations to the Command-and-control (C2) functions in a battle.

CPT Short developed his C2 MOE at three levels of effectiveness spanning the force level down to the individual level (see figure 1). Since EAGLE represents a low-resolution model, we applied the C2 MOE levels of *Force Effectiveness* and *Mission Effectiveness*.

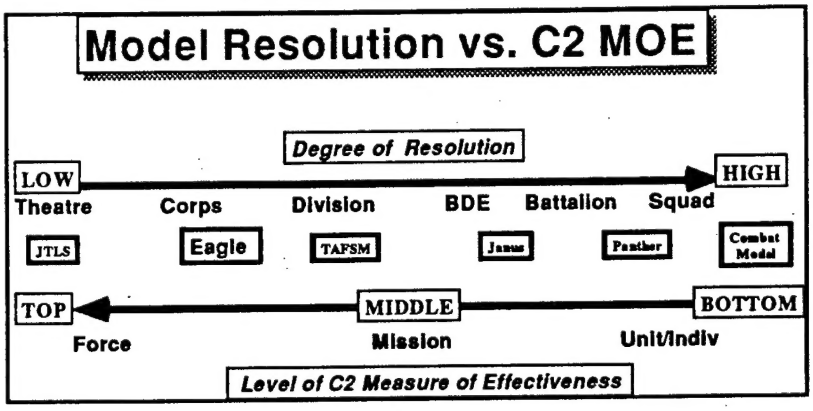

Figure 1. Comparing Resolution with MOE Levels

[1]"Command and Control Measures- A Proposed Approach", CPT Robert Short.

CPT Robert Short describes a "structured resolution approach" with the top level evaluating "contribution to overall force effectiveness", hence, the *Force Measure of Effectiveness.*[2] To describe C2 MOE at the mid-level of resolution, the *Mission Measure of Effectiveness* is "the force's accomplishment of mission objectives" described in terms of the four tenets of Airland Battle - agility, initiative, depth and synchronization.[3] Various C2 Measures of Effectiveness are contained in these categories (Appendices A and B). The same procedures applies to other combat simulations which use C2 MOE. Appropriate C2 levels will be chosen based on the model's resolution as seen in figure 1.

C2 Measures of Effectiveness.

An "MOE should be a 'robust' quantitative expression of the degree to which the system under evaluation meets its objectives."[4] Whenever analysts configure alternatives for combat simulations, they seek meaningful MOE to find an absolute value and/or relative comparison of those alternatives.

In the field of combat models, there is an increasing trend towards quantifying not only MOE for combat system parameters, but also those MOE which assess command-and-control effects on the battlefield. TRADOC Analysis Command (TRAC) and Los Alamos National Laboratory (LANL) are currently developing Eagle. As an object-oriented, low-resolution, deterministic model, Eagle will integrate command-and-control functions and plans into Corps/Division-level battles. Including command-and-control creates a new dimension for the analyst to evaluate in a model's results. Output data now include the interactions and effects of numerous command decisions, control measures and operational plans.

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[2]Short, p. A-1.
[3]Short, p. A-1.

4 DARCOM-P 706-102, Nov. 79, p. 26-1.

The Methodology.

As already suggested, defining performance measures is not an easy task. The authors reviewed and applied CPT Short's proposed methodology as part of their Combat Modeling summer research at the TRADOC Analysis Command (TRAC). One of the research objectives was to learn the object-oriented database and artificial intelligence applications within Eagle. Assessing C2 MOE for Eagle was the means by which I sought to achieve my objective. The opportunity to work alongside the Eagle development team at TRAC enhanced our learning of the conceptual design and current code configurations for the Eagle model.

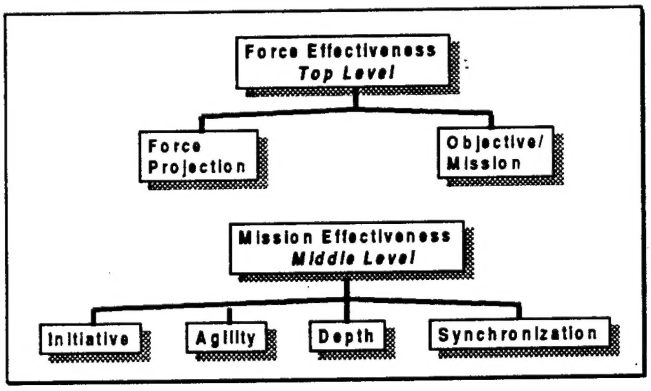

Figure 2 . Eagle's Levels of Measures of Effectiveness

The methodology for applying C2 MOE in Eagle follows: 1) Define the level of performance measures needed for analysis (figures 1 and 2) ; 2) From the organizational charts in Appendices A and B, select MOE which are independent and measurable; 3) Follow the MOE definition format in Appendix C; and 4) Graph and tabulate the statistics using the MOE values from the model as a basis for comparing alternatives.

1) Define the level of performance measures needed for analysis (Appendix A):

Since Eagle is a Corps/Division-level simulation, there are two levels of MOE which apply. First of all, the "Force Effectiveness" level includes those measures which assess how well the entire Force accomplishes certain actions. "Mission Effectiveness" applies to more specific MOE under the Airland Battle Operation tenets of Initiative, Agility, Depth and

Synchronization to measure mission success. [5] For a study, it may be necessary to choose MOE from several levels to assess C2 at different echelons within the force's organization.

2) From the organizational charts defined in Appendices A and B, select MOE which are independent and measurable:

The concept of independence among MOE is beneficial so that MOE portray distinct facets of the battlefield. Avoid redundancy by selecting MOE which apply different quantitative parameters. This will enable a better overview of how the battle occurred.

Even though MOE appear quantifiable, computer-coded post-processing limitations sometimes prohibits measurements of certain MOE. Specific MOE definitions specify the output desired. The MOE output should be available from the simulation post-processing files.

3) Follow an MOE definition format (Appendix C):

Efforts to generically define MOE may one day validate comparison of results among several combat models. The analyst may also decide to put the MOE into context.[6] For the Eagle Model, dividing the battle into natural divisions (i.e.- battlefield events) enables one to assess the C2 at various phases of the battle.

For every study, requirements often call for revised definitions of the measures of effectiveness. The analyst who uses a prescribed MOE definition format will be able to quickly adjust a previously-used MOE to apply to the study at hand. Proper documentation of MOE will facilitate efforts in future studies. In time the development of a generic and universally-agreeable set of C2 MOE could reduce the workload for everyone.

4) Conduct graphical and statistical analysis of the C2 MOE output:

Every analyst must ensure the decision-maker clearly understands the basis for a study's recommendations. Eagle provides output data which are transferable to graphics

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[5]Short, p. A-1.

[6]For the Eagle example, it was LTC John Ogren's idea to divide the battle into the following phases: Passage of Lines, Attack at the FEBA and Exploitation/Pursuit.

and statistical programs. While conducting the graphical analysis, we analyzed whether the output data (MOE) was sensitive to changes made in input parameters, such as command-and-control of the unit. Statistical analysis using nonparametrics assisted us in gaining confidence in the data. If the input parameter changes are ill-represented by the C2 MOE, it may be necessary to choose another MOE or conduct more runs.

Conclusions/Recommendations for Future Work.

As a working paper, this report focuses on command-and-control models and MOE to suggest specific procedures to handle a new era in combat modeling analyses. With the advent of the new Eagle combat model, the time is right for rekindling interest in an area which is often vague, intangible and neglected. CPT Short has proposed a method to link operational command-and-control doctrine to measuring performance of leaders and control within a model. The integration of C2 doctrine into C2 MOE assesses a model's utility and validity. Eagle incorporates command-and-control functions into the decision cycles for combat. Therefore, it is a very appropriate model for solidifying the linkage between doctrine and the combat output data measures.

A defined accreditation process will ensure validation for both the decision-makers and the analysts. Accreditation would include the following actions: 1) Select other MOE related to the Airland Battle tenets and evaluate their utility; 2) Obtain data from additional Eagle simulation runs to improve and develop the application of the methodology to both the offense and defense; and 3) Apply this methodology to other C2 combat models from squad to corps levels.

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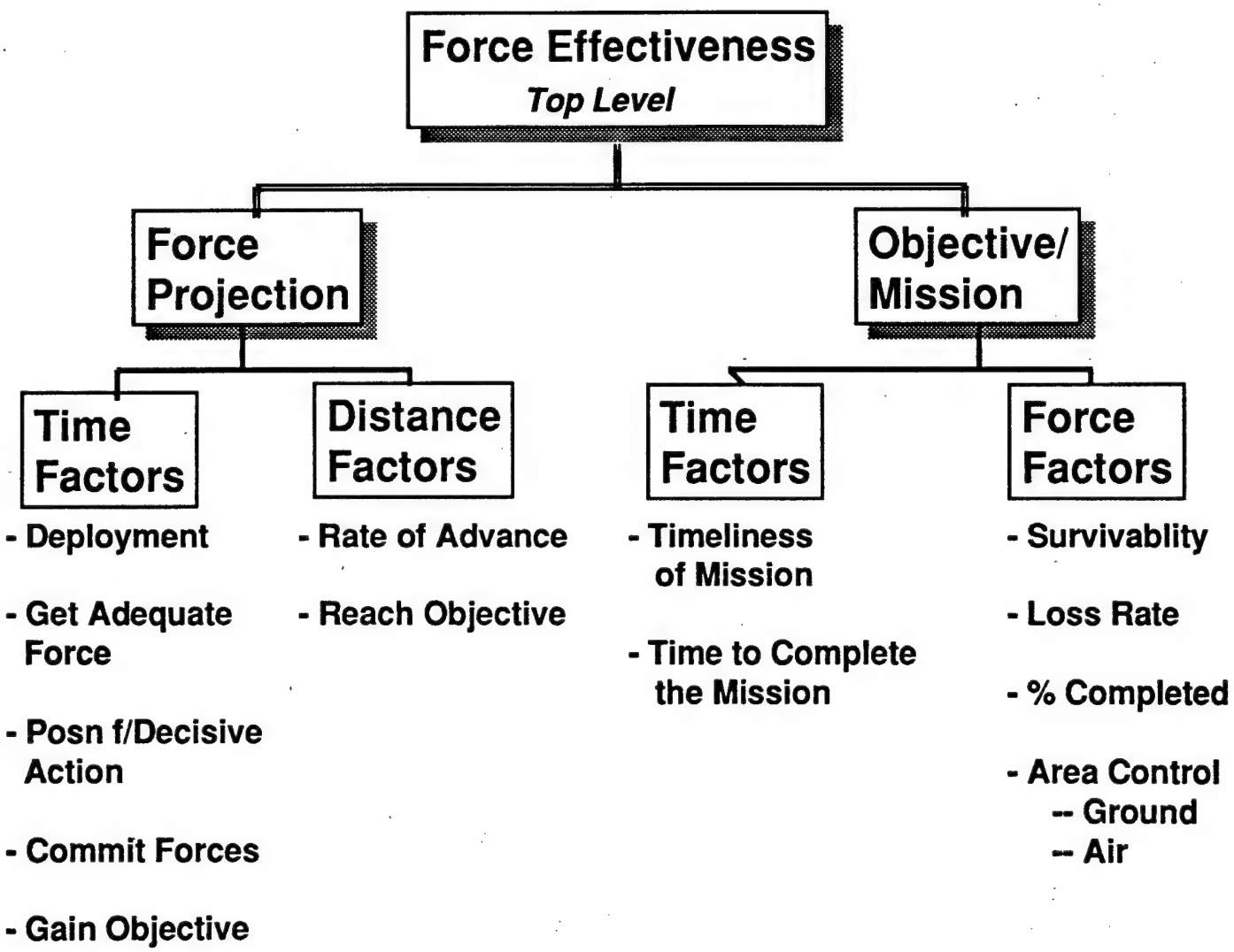
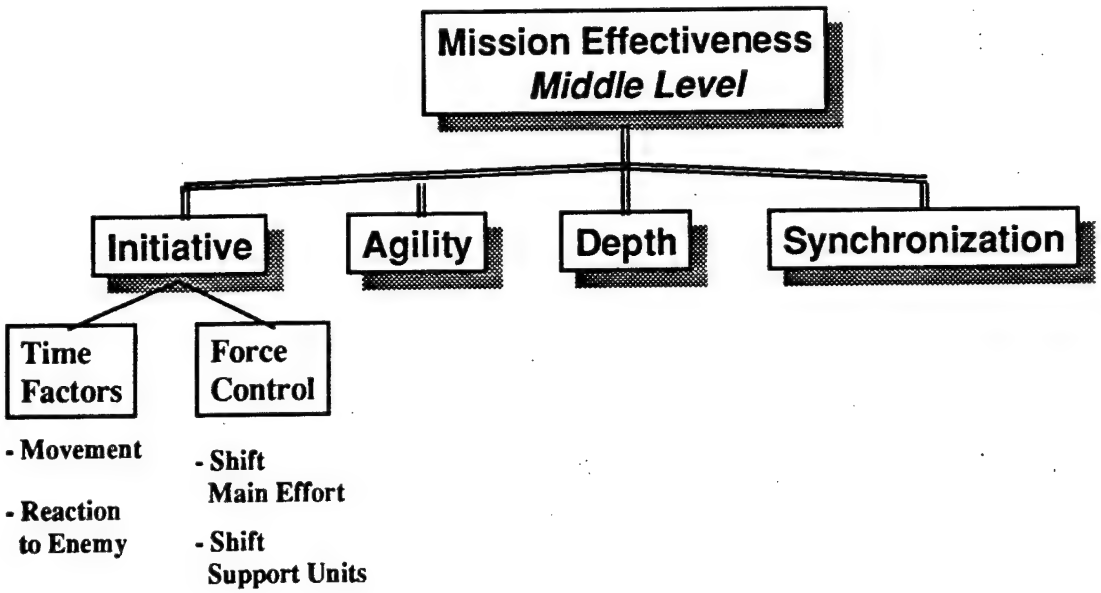
Short, Robert. "Command-and-Control Measures: A Proposed Approach." Fort Leavenworth, KS: U.S. Army TRADOC Analysis Command, 1991.

APPENDICES

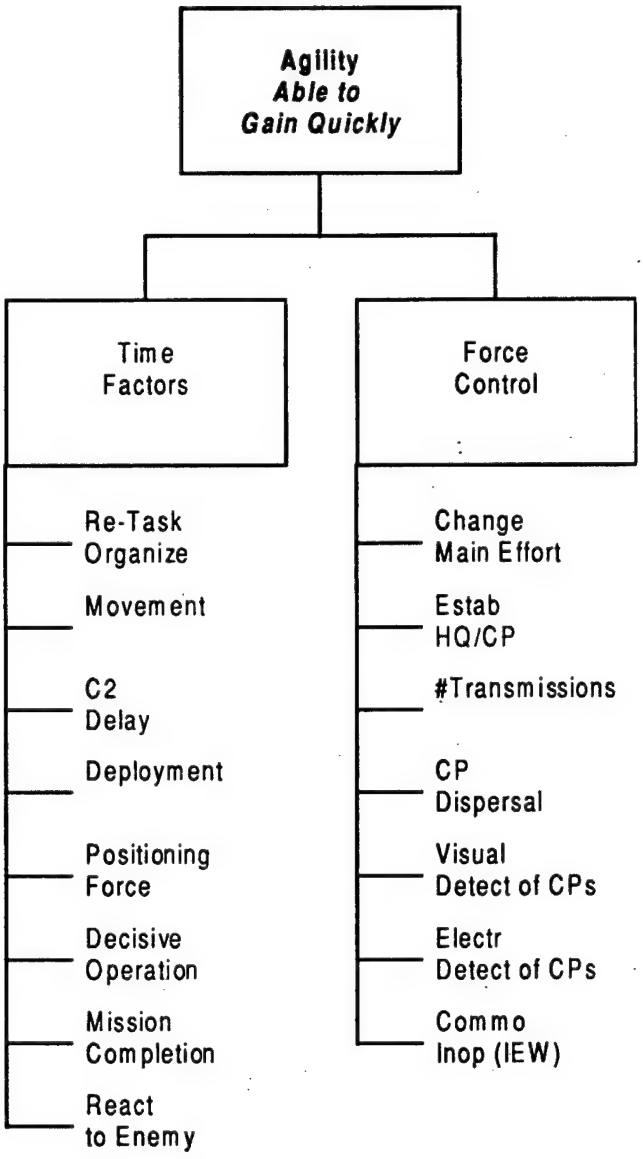
Appendix A: Force Effectiveness C2 MOE



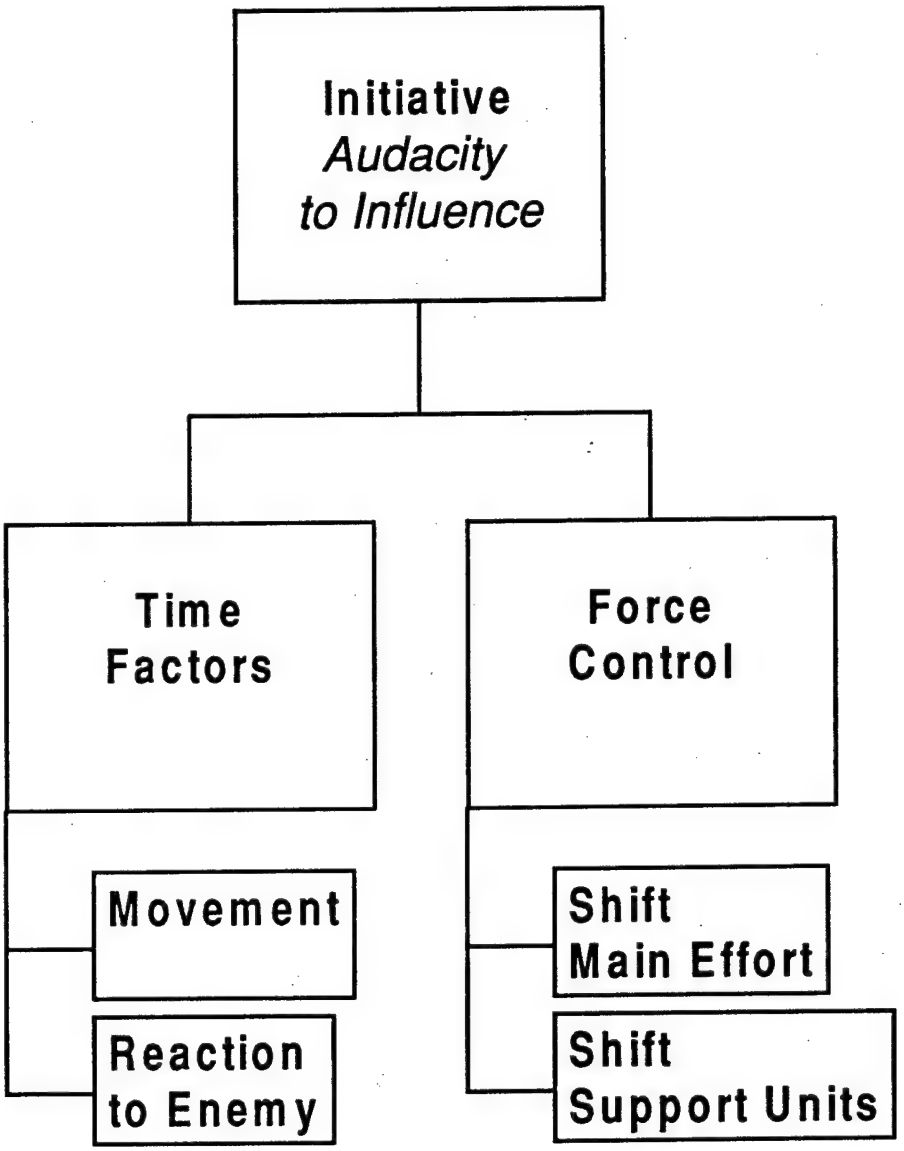
Mission Effectiveness
MOE for Eagle



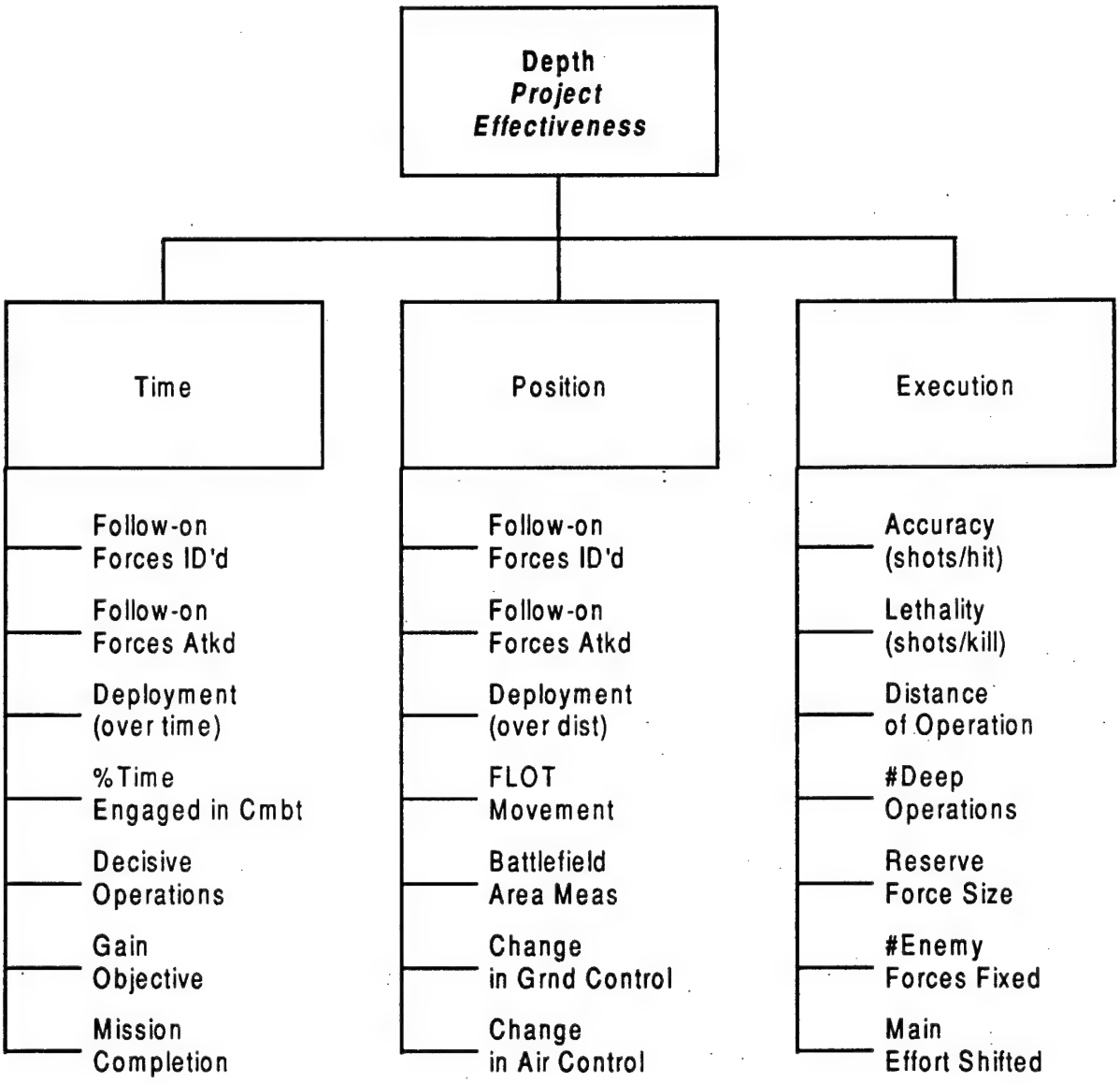
APPENDIX B- Middle Level MOE (Agility)



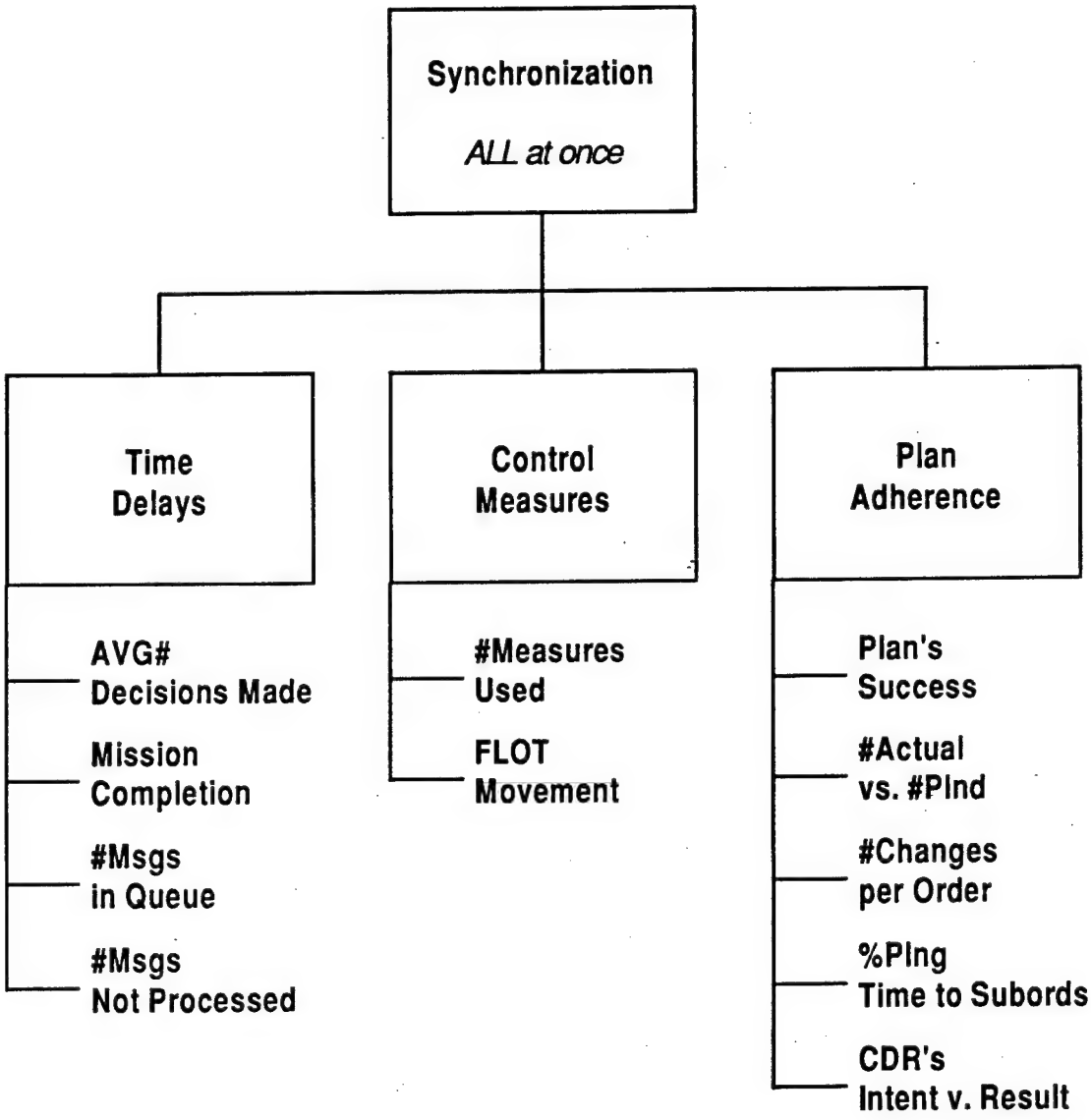
APPENDIX B- Middle Level MOE (Initiative)



APPENDIX B- Middle Level MOE (Depth)



APPENDIX B- Middle Level MOE (Synchronization)



APPENDIX C- Command-and-control Measures of Effectiveness (Used for the Eagle Combat Model)

I. Force Effectiveness

A. MOE #1: Rate of Advance

1. Definition- The rate at which the force moves from its initial deployment positions to various phases of the battle.

2. Dimension- Expressed in terms of kilometers per hours (or other appropriate rate measurement).

3. Limits on Range- A positive value with an upper limit of the rate of the slowest unit in the force being studied.

4. Rationale- Examines the force's ability to project itself into the battle

5. Relevance- Measures the effectiveness of commanders to move units through the battlefield

6. Associated MOE- Time to each phase; Distance to objective(s)

7. References- "Eagle Combat Simulation Prototype", by LTC John W. Ogren, TRAC-F-TM-0689, August 1989.

B. MOE #2: Timeliness of Mission Events

1. Definition- The time it takes for the force to conduct its overall objectives throughout various phases of the battle.

2. Dimension- Expressed in units of time as a single value or a fraction of mission time divided by total battle time.

3. Limits on Range- A positive value with an upper limit of the total battle time.

4. Rationale- Examines the force's ability to conduct phases of the battle in a relatively efficient manner.

5. Relevance- Measures the effectiveness of command-and-control during certain phases of battle.

6. Associated MOE- Distance to objective(s); Time to complete overall force mission.

7. References- "Eagle Combat Simulation Prototype", by LTC John W. Ogren, TRAC-F-TM-0689, August 1989.

C. MOE #3: Proportion of Blue Force Surviving

1. Definition- The quantity of the force available to continue the overall mission throughout various phases of the battle.

2. Dimension- Expressed as a fraction or percentage of remaining strength divided by initial force strength. Units can be weighted as desired.

3. Limits on Range- A positive fraction or percentage value with an upper limit of 1.0 or 100%.

4. Rationale- Tracks the force's capability to conduct its overall mission at certain phases of the battle.

5. Relevance- Provides results of command-and-control decisions and actions during the battle.

6. Associated MOE- Fraction Exchange Ratio; Loss Exchange Ratio.

7. References- "Eagle Combat Simulation Prototype", by LTC John W. Ogren, TRAC-F-TM-0689, August 1989; DARCOM-P 706-102.

II. Mission Effectiveness

A. MOE #1: Average Number Decisions Made

1. Definition- The average amount of decisions the force's leaders make going from initial deployment positions to various phases of the battle.

2. Dimension- Expressed in terms of average number of decisions per minute.

3. Limits on Range- A positive value with no specified upper limit.

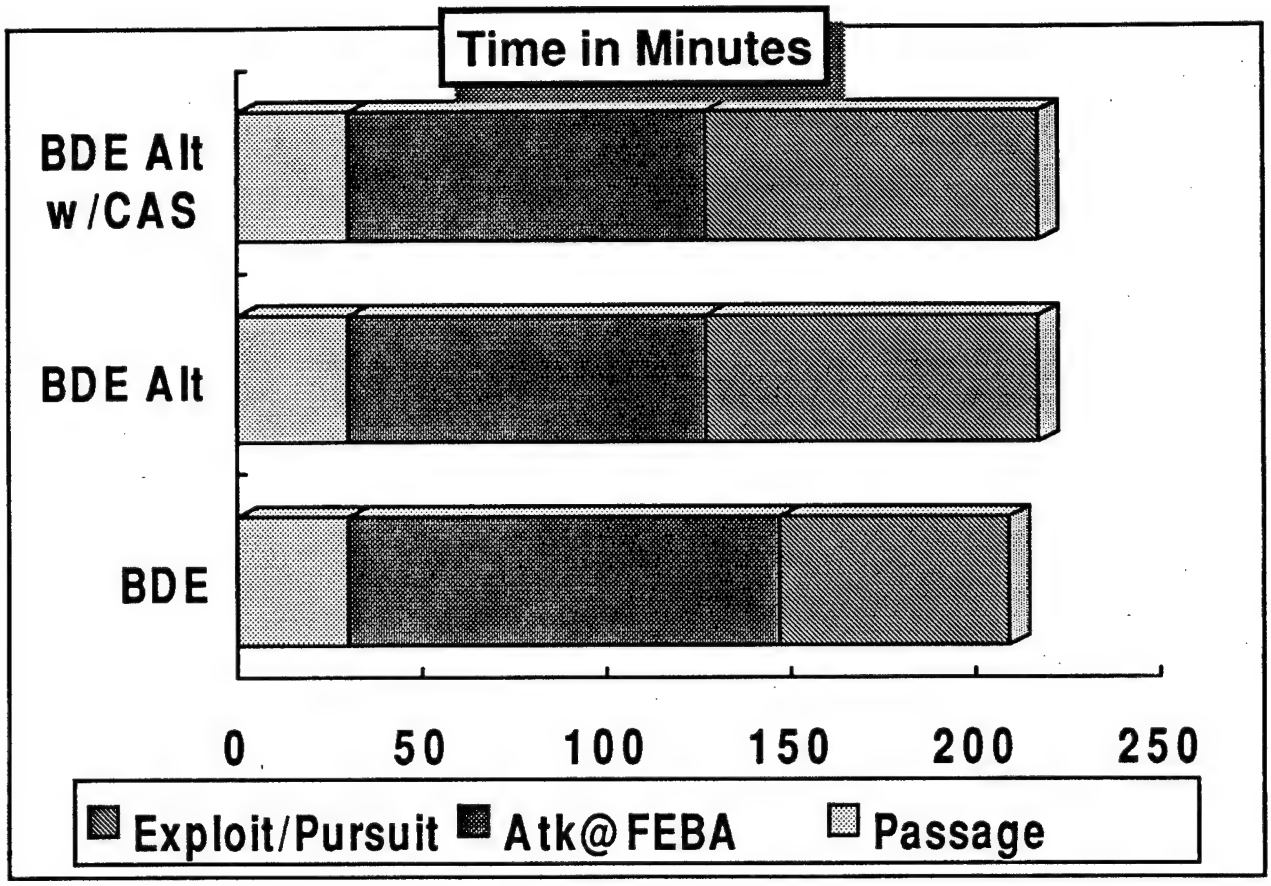
4. Rationale- Examines the quantity of decisions which must be made at certain points in the battle.

5. Relevance- Measures the commander's effectiveness to control units with minimal supervision throughout the battlefield.

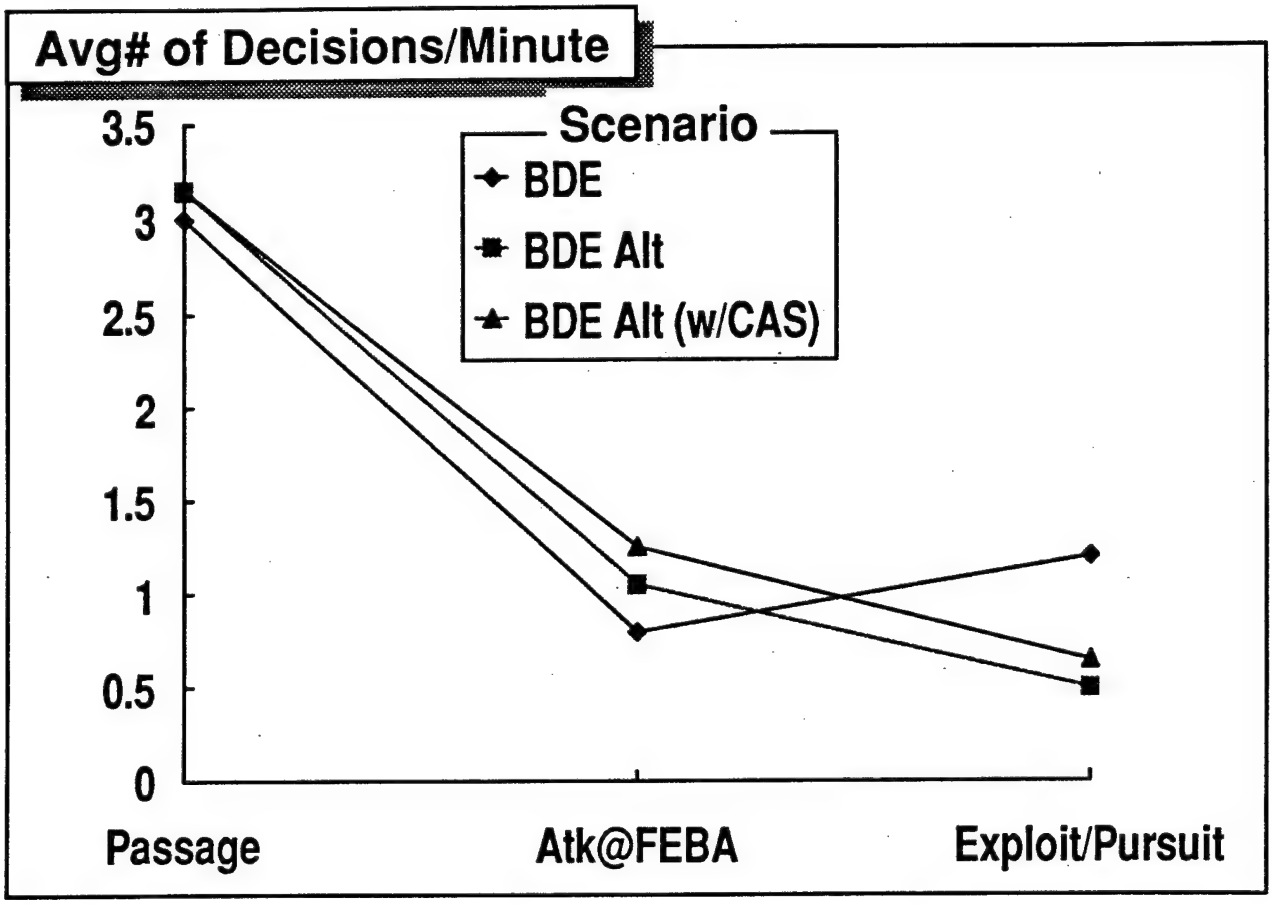
6. Associated MOE- C2 Delay; #communications messages in queue.

7. References- "Eagle Combat Simulation Prototype", by LTC John W. Ogren, TRAC-F-TM-0689, August 1989.

Battle Duration



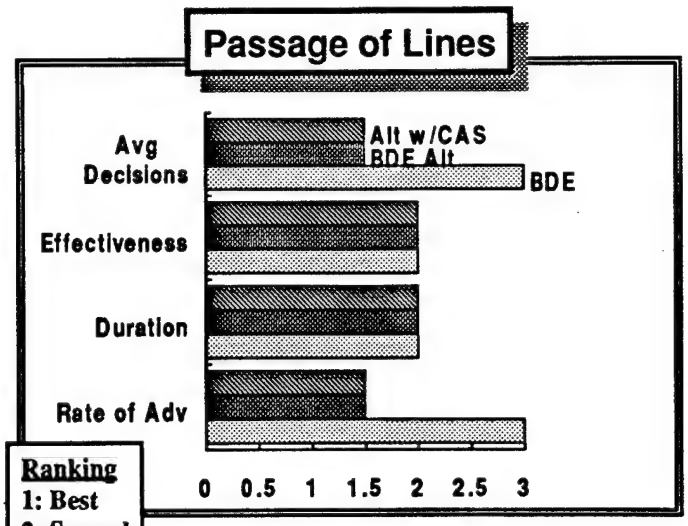
Decisions Made in Combat



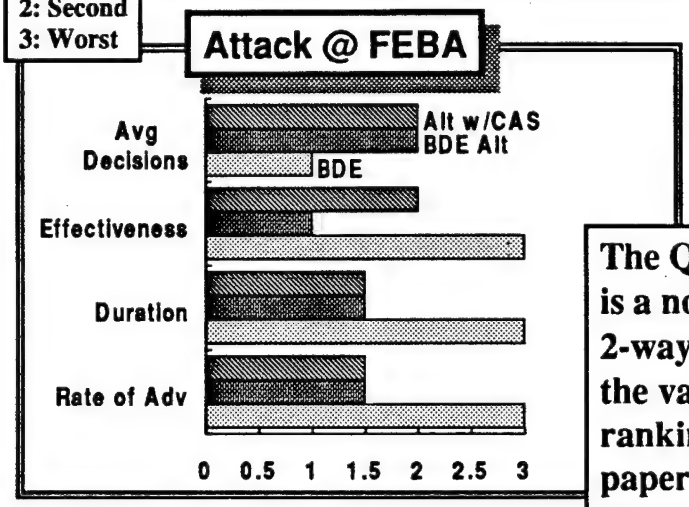
Appendix D: Eagle C2 MOE Analysis

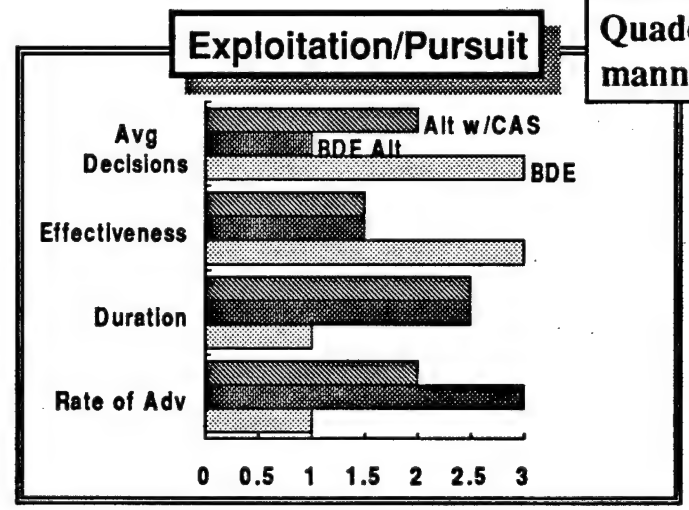
All 3 Scenarios were compared by ranking their MOE.

All MOE were weighted equally.



Ranking
1: Best
2: Second
3: Worst





The Quade Test is a nonparametric 2-way analysis of the variance of the rankings. CDT Jones' paper in Appendix E illustrates using the Quade Test in this manner for Eagle.

Appendix E: Cadet Omar Jones' Research on C2 MOE for Eagle

Cadet Omar Jones worked at TRAC with the Eagle development team for approximately three weeks. As an Operations Research major, Cadet Jones was interested in the combat simulation model. As a future leader of the corps of cadets, Cadet Jones was equally interested in command-and-control modeling.

His efforts are very thorough and well-done considering he is beginning the last year of his undergraduate level education. His analysis and research demonstrate the potential and abilities possessed by most undergraduates at the United States Military Academy.

Acknowledgements

Captain George Stone, Department of Systems Engineering at the United States Military Academy, was my primary source for information and guidance. His research into measures of effectiveness for command-and-control provided the basis for my work.

Lieutenant Colonel John Ogren, from the Operations Analysis Center at Fort Leavenworth, Kansas, provided the data from the Eagle Combat Simulation for both Captain Stone and myself. His constant expertise and knowledge about the Eagle model proved invaluable.

Command and Control Measures of Effectiveness for the Eagle Combat Simulation

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D4 '92
AEP 1991
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TABLE OF CONTENTS

INTRODUCTION: This analysis is a continuation of work completed by CPT G. Stone in his paper entitled "A Methodology For Defining Command and Control Measures of Effectiveness in the Eagle Combat Simulation." Given CPT Stone's methodology and data, three additional measures of effectiveness were developed. These measures further evaluate command and control (C2) in the Eagle Combat Simulation.

THE METHODOLOGY: The method used to define the measures of effectiveness is based on a format described in "Force Developments: The Measures of Effectiveness" (USACDC PAM 71-1). This resource develops a method of defining measures of effectiveness and provides a "compendium of measures of effectiveness" (A-1). These measures are broken into ten categories (see ANNEX E), to include Command and Control. But, only six measures for C2 are examined (see ANNEX F). Hence, the need for this study.

Also included in "Force Developments" is a seven step method for defining and describing measures of effectiveness. This method is highlighted in ANNEX G and is self-explanatory. It allows all measures to be explicitly explained and evaluated.

THE DATA: The data used included output from one Eagle scenario run with three different alternative units. The first case was a baseline brigade. The second and third case were, respectfully, a brigade alternative (helicopters were added to the inventory) and a brigade alternative with close air support. The data includes the number of command decisions, the number of subordinate decisions, number of effective vehicles, percent of vehicles effective, and the time divided into five minute intervals. Each set of data was divided into three phases based on the scenario. The phases were the movement to passage, attack at the FEBA, and the exploitation.

THE ANALYSIS: Three measures of effectiveness were developed and tested using this data. The development and testing of each measure is contained in ANNEXES A through C. The development was based on current U.S. Army doctrine, and the measures were tested using non-parametric methods, specifically the Quade Test which tests data in a complete randomized block design. The three measures developed were:

1) Number of decisions by commander per five-minutes
2) Percent vehicles effective after each phase
3) Average time between destruction of friendly vehicles

CONCLUSIONS: Specific conclusions for each measure of effectiveness with relative significance are included in the ANNEXES. Overall, the brigade baseline was less efficient for effective command and control than either alternative.

The addition of close air-support to the brigade alternative did not produce a statistically significant advantage based on these three measures. Based on these measures, the brigade alternative is the best force mix for effective command and control.

The measures of effectiveness developed followed directly from Airland Battle tenants and supported Army doctrine. Although the number of command decisions showed no statistical difference for these alternatives, this measure is the most applicable for command and control. The other measures look at command and control indirectly through unit performance on the battlefield.

ANNEX A: MOE #1 - Number of Command Decisions per 5 Minute Interval

DEFINITION OF MEASURE: The data from the Eagle post-processor includes the number of decisions made by the commander and the number of decisions made by the subordinate commanders. These values are given for every five-minute time interval during a scenario. This scenario was divided into three phases (Movement to Passage, Attack at the FEBA, and Exploitation). By analyzing the number of decisions made by the commander in each phase, ineffective or inefficient trends can be uncovered.

DIMENSION OF MEASURE: The MOE is expressed as an average number of decisions per five-minute interval for each phase.

LIMITS ON THE RANGE OF MEASURE: The minimum value is zero decisions and there is no maximum limit.

RATIONALE FOR THE MEASURE: This MOE is rooted in the Airland Battle tenets of Agility, Initiative, and Synchronization. FM 100-5 *Operations* states that "it is essential to decentralize decision authority to the lowest practical level because overcentralization slows action and leads to inertia. At the same time, decentralization risks some loss of precision in execution. The commander must constantly balance these competing risks, recognizing that the loss of precision is preferable to inaction" (15). Also, fewer decisions by the commander allows subordinate units to "decide quickly, and act without hesitation. Formations at every level must be capable of shifting the main effort with minimum delay and with the least possible necessity for reconfiguration and coordination" (16). Finally, "commanders need not depend on explicit coordination if all forces involved fully understand the intent of the commander, and if they have developed and rehearsed well-conceived standard responses to anticipated contingencies" (17). In short, an alternative which requires more decisions by the commander than the baseline unit violates the tenets of Army doctrine and is inefficient.

RELEVANCE OF THE MEASURE: If any alternative requires a statistically significant increase in the number of decisions required by the commander, that alternative should be rejected as inefficient and ineffective for proper command and control.

ASSOCIATED MOE:
- Repetitions per order
- Changes per order
- Mean dissemination time
- Percent planning time forwarded

REFERENCES: FM 100-5 *Operations*

Force Developments: The Measures of Effectiveness

MOE #1 # of Command Decisions per 5 Minutes

	ALT #1	ALT #2	ALT #3	Total
Movement to Passage	1.80	1.80	1.80	5.40
Attack at FEBA	0.63	0.65	0.70	1.98
Exploitation	0.50	0.11	0.11	0.72
Total	2.93	2.56	2.61	8.10

RANKS

	ALT #1	ALT #2	ALT #3	Range	Rank
Movement to Passage	2.00	2.00	2.00	0.00	1.00
Attack at FEBA	1.00	2.00	3.00	0.07	2.00
Exploitation	3.00	1.50	1.50	0.39	3.00

STATISTICS

	ALT #1	ALT #2	ALT #3
Movement to Passage	0.00	0.00	0.00
Attack at FEBA	-2.00	0.00	2.00
Exploitation	3.00	-1.50	-1.50
Sj	1.00	-1.50	0.50

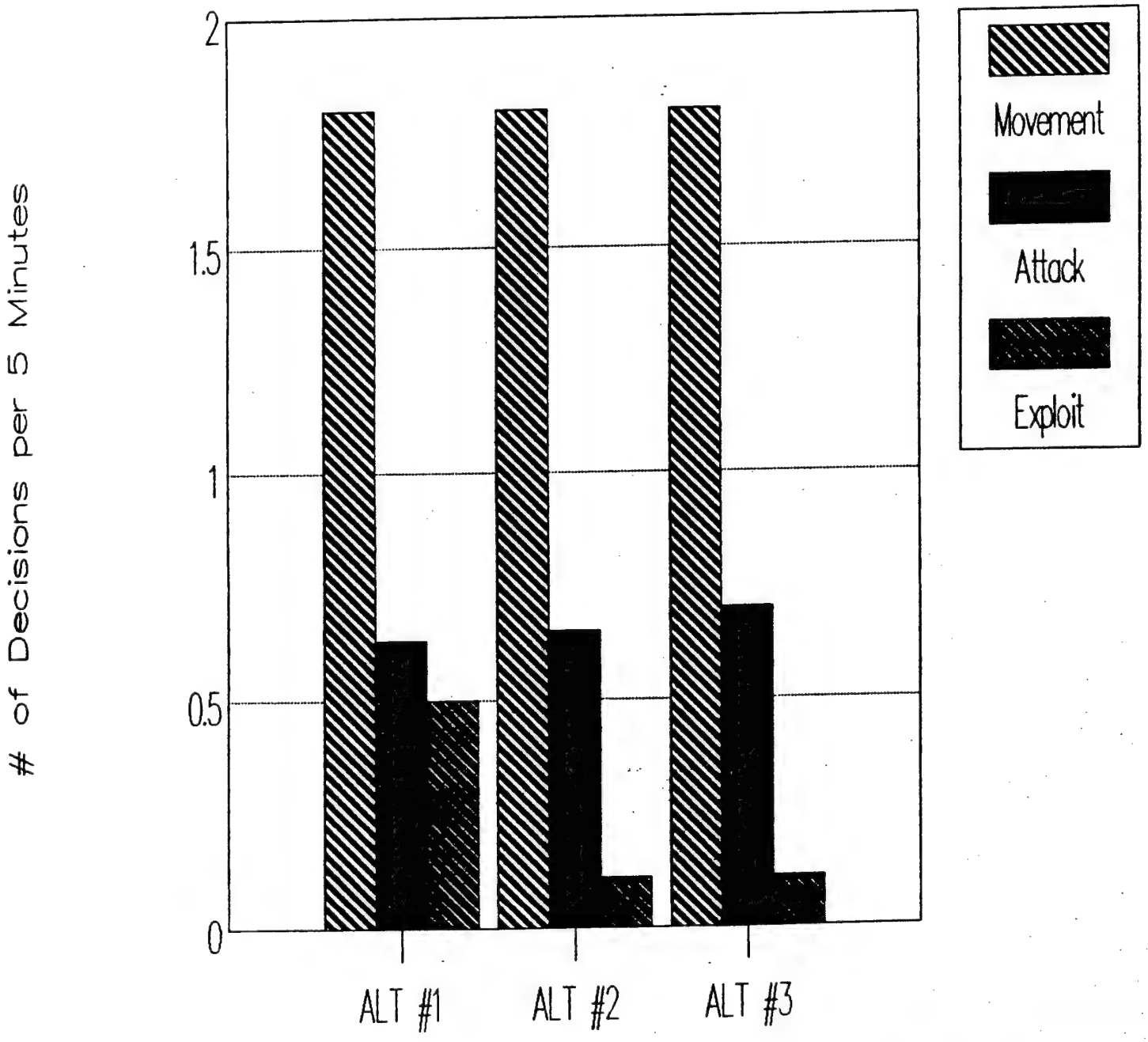
A1 = 21.50
B1 = 1.17
T1 = 0.11

CONCLUSIONS

Since the statistic T1 is only 0.11475, which is less than any appropriate F-statistics at a level less than 25% significance, the null hypothesis will not be rejected. In this scenario, the number of command decisions does not demonstrate a significant difference among the alternatives in effective command and control.

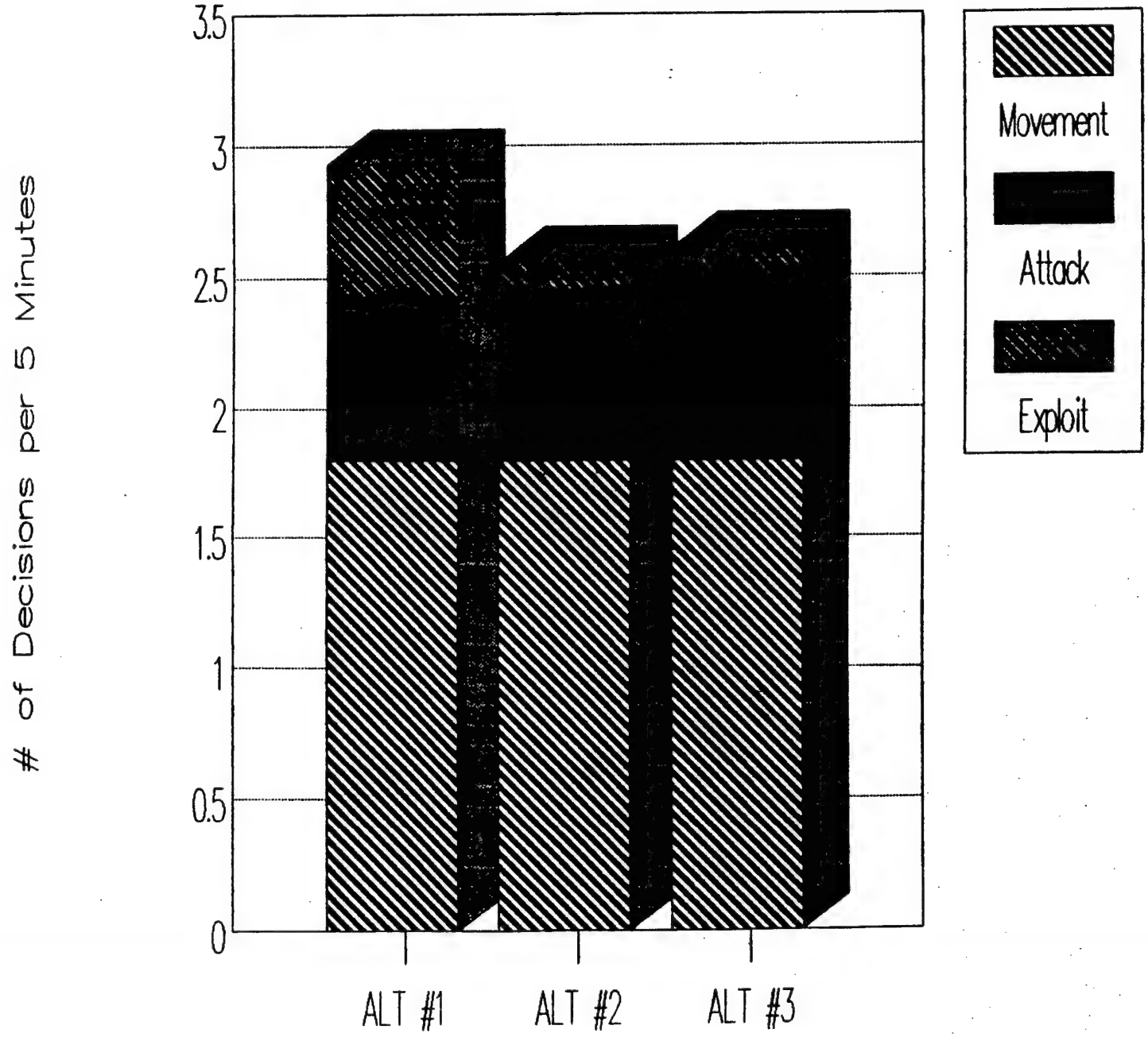
Eagle C2

MOE #1



Eagle C2

MOE #1



ANNEX B: MOE #2 - Percent Vehicles Effective After Phase

DEFINITION OF MEASURE: Percent of total vehicles effective after the movement to passage, the attack at the FEBA, and the exploitation of the attack.

DIMENSION OF MEASURE: Expressed as a percentage representing a ratio between effective vehicles and total vehicles beginning the scenario.

LIMITS ON THE RANGE OF MEASURE: This MOE can range from zero to a maximum of 100%, assuming no additional units or vehicles are added after the attack begins.

RATIONALE FOR THE MEASURE: It is important for a unit to have maximum war-fighting capacity during all phases of the attack. Rarely will a unit lose vehicles during the movement to passage. It is critical that a unit have a maximum number of effective vehicles before the exploitation of the attack and at the conclusion of the battle. According to FM 100-5 *Operations*, "exploitation of depth demands imagination, boldness, foresight, and decisiveness in leaders. Commanders must see beyond the requirements of the moment, actively seek information on the area and the enemy in depth, and employ every asset available to extend their operations in time and space" (17). It is essential that a maximum number of vehicles remain effective to provide this response. "While exploitation is integral to every attack, it is especially important in a deliberate attack in which concentration for the attack may require accepting risk elsewhere. Failure to exploit success aggressively may permit the enemy time to detect and exploit that weakness, and thus regain the initiative and advantage (100). "Every attack not restricted by higher authority or lack of resources should therefore be followed without delay by bold exploitation designed to keep the enemy under pressure, compound his disorganization, and erode his will to resist" (100). Finally, "exploitation is the bold continuation of an attack following initial success, pursuit, the relentless destruction or capture of fleeing enemy forces who have lost the capability to resist" (117). Therefore, it is critical that a unit maintain maximum strength throughout an engagement, not only to save its men and material resources, but to exploit the attack.

RELEVANCE OF THE MEASURE: The most effective unit will survive the initial phases of the attack and press its advantage during the exploitation phase with the maximum amount of combat power. Those units which lose a statistically significant percentage of their vehicles are less desirable than those which retain a larger number of vehicles.

ASSOCIATED MOE: Casualty rate
Attrition rate
Force effectiveness indicator
Probability of success

REFERENCES: FM 100-5 *Operations*
Force Developments: The Measures of Effectiveness

MOE #2: Percent Vehicles Effective After Phase

	ALT #1	ALT #2	ALT #3	Total
Movement to Passage	100.00	100.00	100.00	300.00
Attack at FEBA	84.00	99.00	98.00	281.00
Exploitation	69.00	98.00	97.00	264.00
Total	253.00	297.00	295.00	845.00

RANKS

	ALT #1	ALT #2	ALT #3	Range	Rank
Movement to Passage	2.00	2.00	2.00	0.00	1.00
Attack at FEBA	1.00	3.00	2.00	15.00	2.00
Exploitation	1.00	3.00	2.00	29.00	3.00

STATISTICS

	ALT #1	ALT #2	ALT #3
Movement to Passage	0.00	0.00	0.00
Attack at FEBA	-2.00	2.00	0.00
Exploitation	-3.00	3.00	0.00
Sj	-5.00	5.00	0.00

A1 = 26.00
B1 = 16.67
T1 = 3.57

Comparisons Between Individual Alternatives

Constant = 3.74

1 vs. 2	10.00	2.67
1 vs. 3	5.00	1.34
2 vs. 3	5.00	1.34

CONCLUSIONS

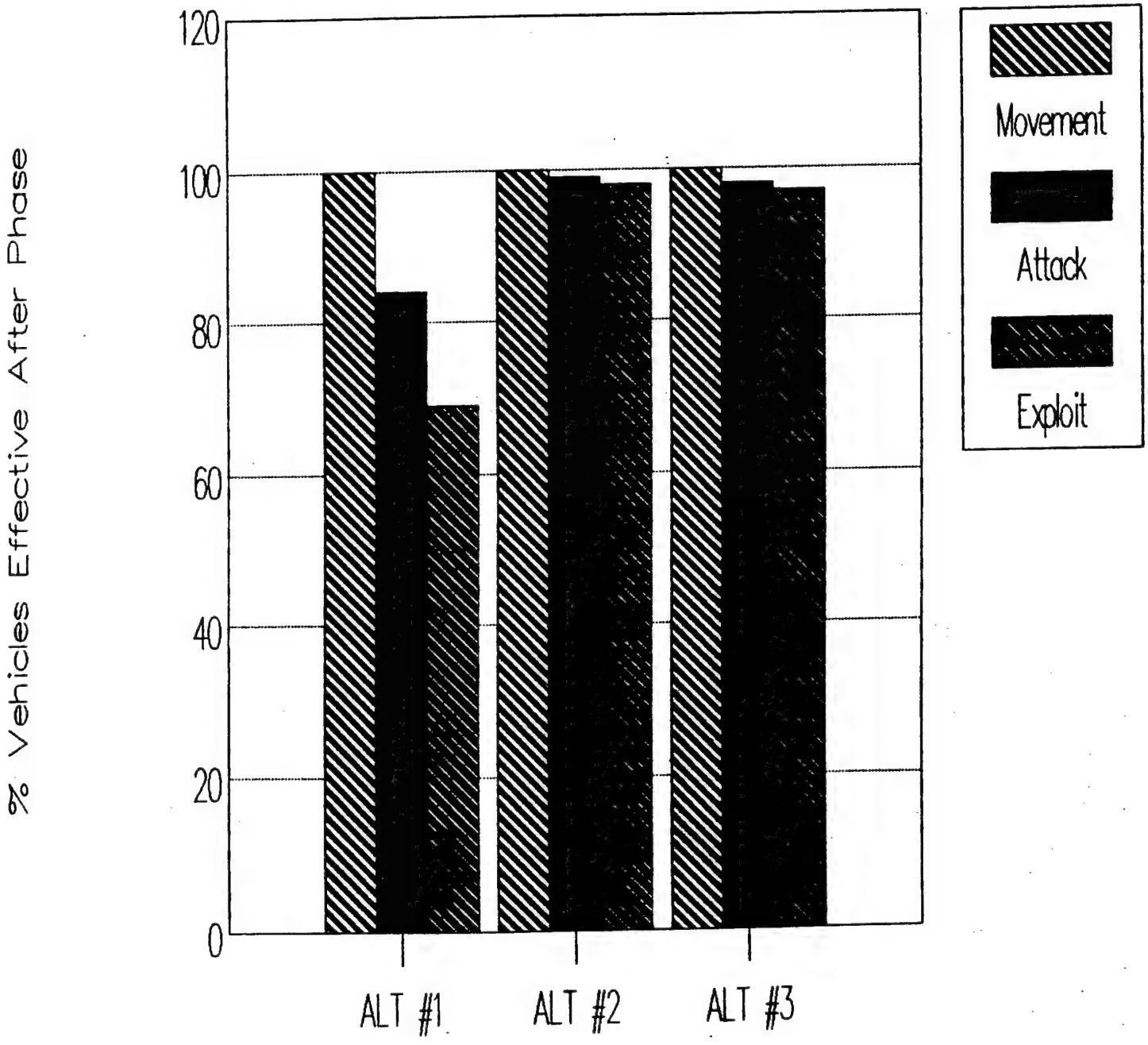
The statistic T1 = 3.5714 and is greater than the F-statistic at 14.84% significance; therefore, the null hypothesis should be rejected at any level of significance greater than 14.84%. One or more of the alternatives have significantly different effective strength at the end of the phases.

Based on the comparisons between individual alternatives, it can be concluded that the brigade baseline and brigade alternate differ with a level of significance less than 3.0%. The brigade alternative with close air support differs from both of the other alternatives with approximately 14% significance. Therefore, the brigade baseline is less effective than the brigade alternate; but the addition of close air support does not greatly increase this level of effectiveness.

The attached graphes visual display this difference. The first alternative can be seen to lose more vehicles than either of the other alternatives.

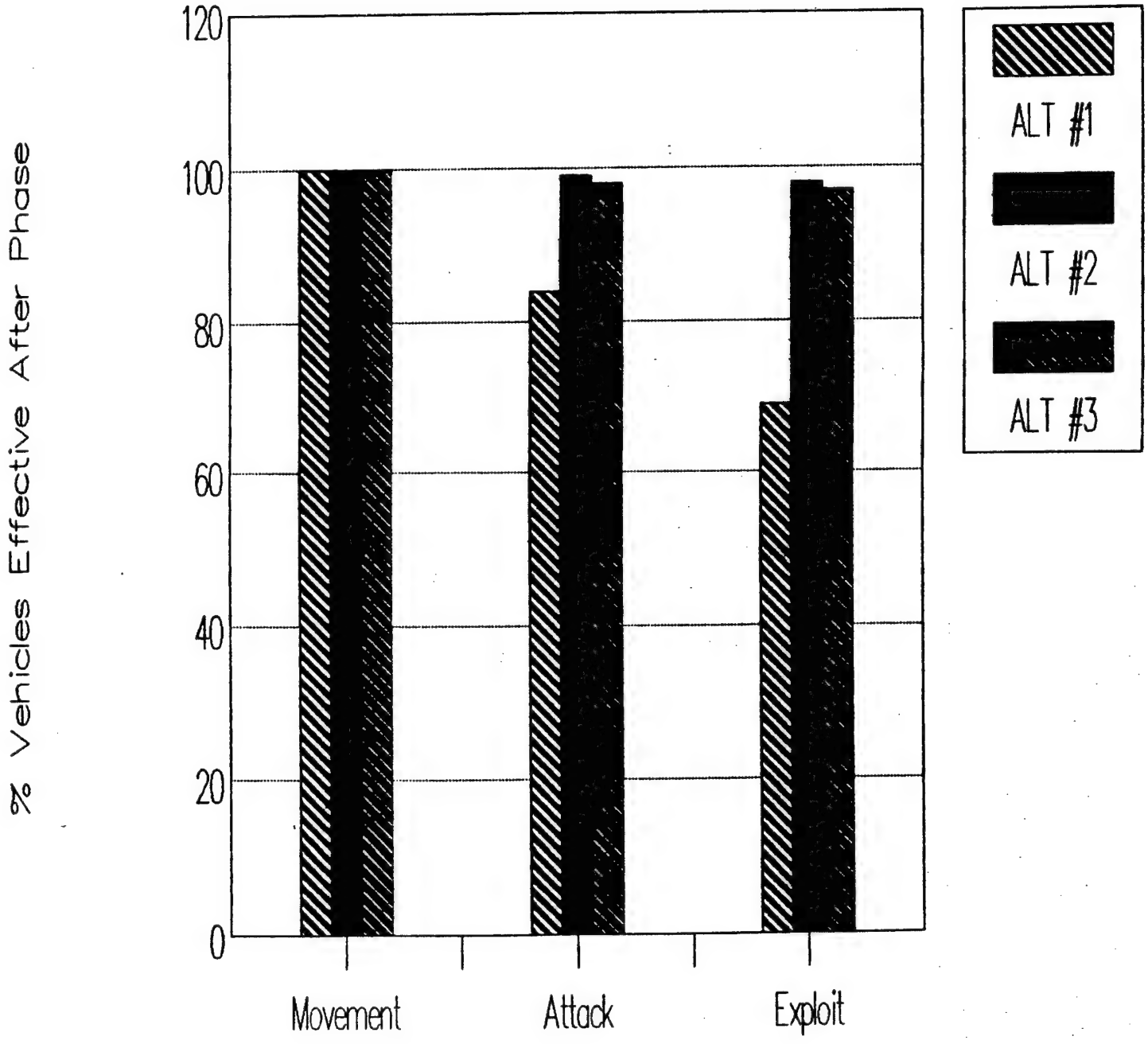
Eagle C2

MOE #2



Eagle C2

MOE #2



ANNEX C: MOE #3 - Average Time Between the Destruction of Friendly Vehicles

DEFINITION OF MEASURE: The average time between friendly vehicles being killed for each of the three phases of the attack.

DIMENSION OF MEASURE: The MOE is expressed as a ratio between the number of friendly vehicles destroyed in a phase compared to the length of the phase as measured in seconds.

LIMITS ON THE RANGE OF MEASURE: The ratio can be as low as zero if no vehicles were destroyed in that phase and as high as the length of the phase if only one vehicle was destroyed. The maximum value is dependent on the length of the scenario.

RATIONALE FOR THE MEASURE: FM 100-5 *Operations* states that "in an offensive campaign, the commander must take care to preserve synchronization and the strength of his force" (112). And, "his aim is to reach his objective with maximum strength as rapidly as possible" (118). This guidance places conflicting demands on the commander to conduct the offensive rapidly but also minimize losses. Both extremely quick and extremely slow offenses can easily result in heavy losses. The commander must find the ideal balance between these demands. The average time between friendly casualties is a good measure of both the pace of the battle and the unit's losses. A low ratio implies that many vehicles were killed per unit of time. This means losses were heavy, the battle was quick, or both. A high ratio implies that the battle was long, losses were light, or both. This information coupled with an evaluation of the percent effective force and the length of the operation gives insight into the command and control of the unit.

RELEVANCE OF THE MEASURE: This MOE "gages the survivability" of the unit (Force Developments, A-41).

ASSOCIATED MOE:
Loss rate
Number losses
Number casualties
Percent casualties

REFERENCES:
FM 100-5 *Operations*
Force Developments: The Measures of Effectiveness

MOE #3: Average Time Between Destruction of Friendly Vehicles

	ALT #1	ALT #2	ALT #3	Total
Movement to Passage	0.00	0.00	0.00	0.00
Attack at FEBA	209.09	2850.00	1140.00	4199.09
Exploitation	139.29	2550.00	2550.00	5239.29
Total	348.38	5400.00	3690.00	9438.38

RANKS

	ALT #1	ALT #2	ALT #3	Range	Rank
Movement to Passage	2.00	2.00	2.00	0.00	1.00
Attack at FEBA	1.00	3.00	2.00	2640.91	2.00
Exploitation	1.00	2.50	2.50	2410.71	3.00

STATISTICS

	ALT #1	ALT #2	ALT #3
Movement to Passage	0.00	0.00	0.00
Attack at FEBA	-2.00	2.00	0.00
Exploitation	-3.00	1.50	1.50
Sj	-5.00	3.50	1.50

A1 = 21.50
B1 = 13.17
T1 = 3.16

Comparisons Between Individual Alternatives

Constant = 3.54

1 vs. 2	8.50	2.40
1 vs. 3	6.50	1.84
2 vs. 3	2.00	0.57

CONCLUSIONS

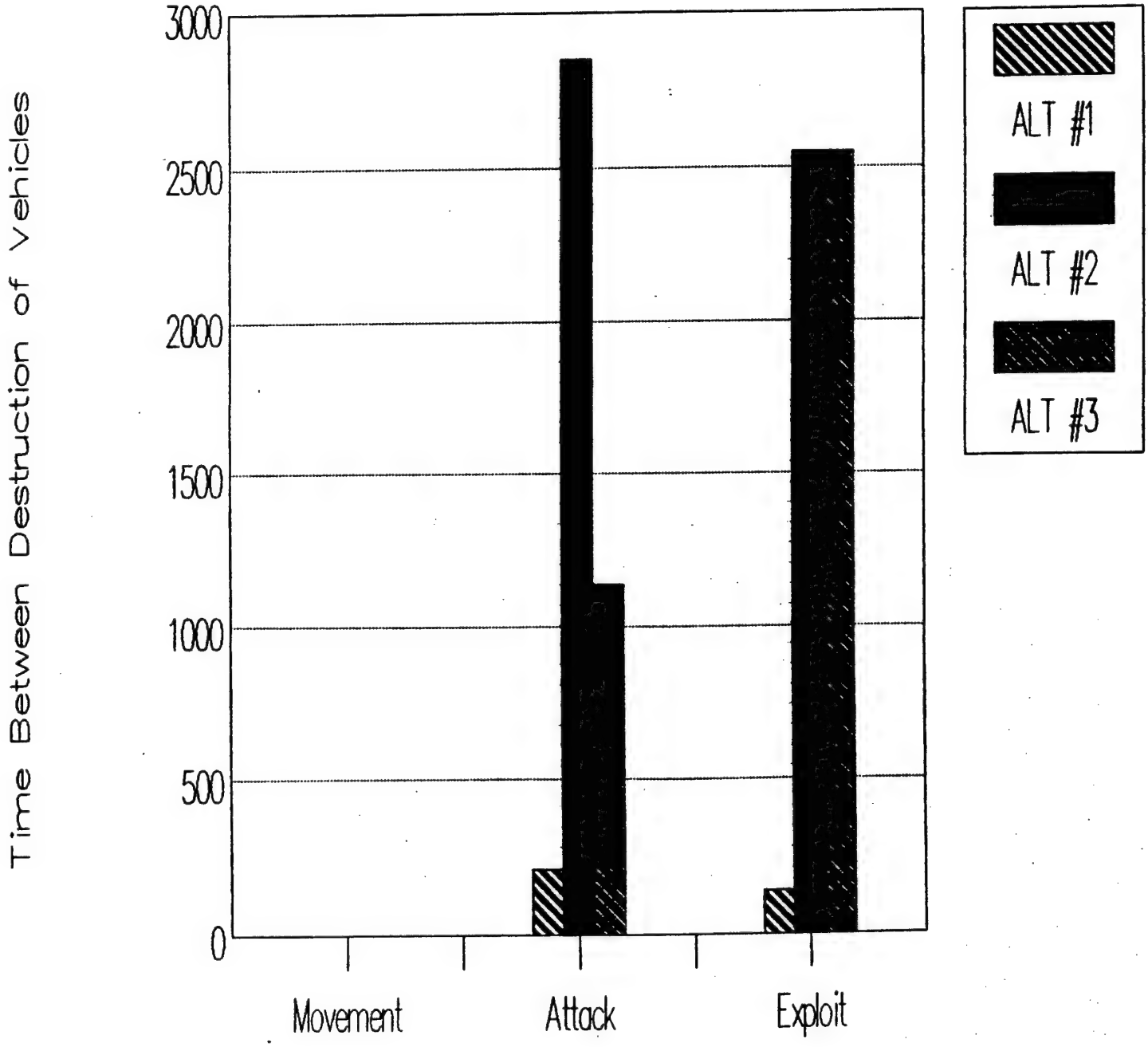
The statistic T1 = 3.1600 and is greater than the F-statistic at 17.50% significance; therefore, the null hypothesis should be rejected at any level of significance greater than 17.50%. One or more of the alternatives have significantly different average time between the destruction of friendly vehicles.

Based on the comparisons between individual alternatives, it can be concluded that the brigade baseline and brigade alternate differ with a level of significance less than 3.96%. The brigade baseline differs from the brigade alternative with close air support with 7.44% significance. The addition of close air support produces no significant difference for the brigade alternate. Therefore, the brigade baseline has a significantly smaller average time between friendly vehicles being destroyed.

The attached graphes visual display this difference. The first alternative can be seen to lose vehicles more rapidly than either of the other alternatives. This may be a result of the extended time required for the brigade baseline to complete the attack as evidenced on the second graph.

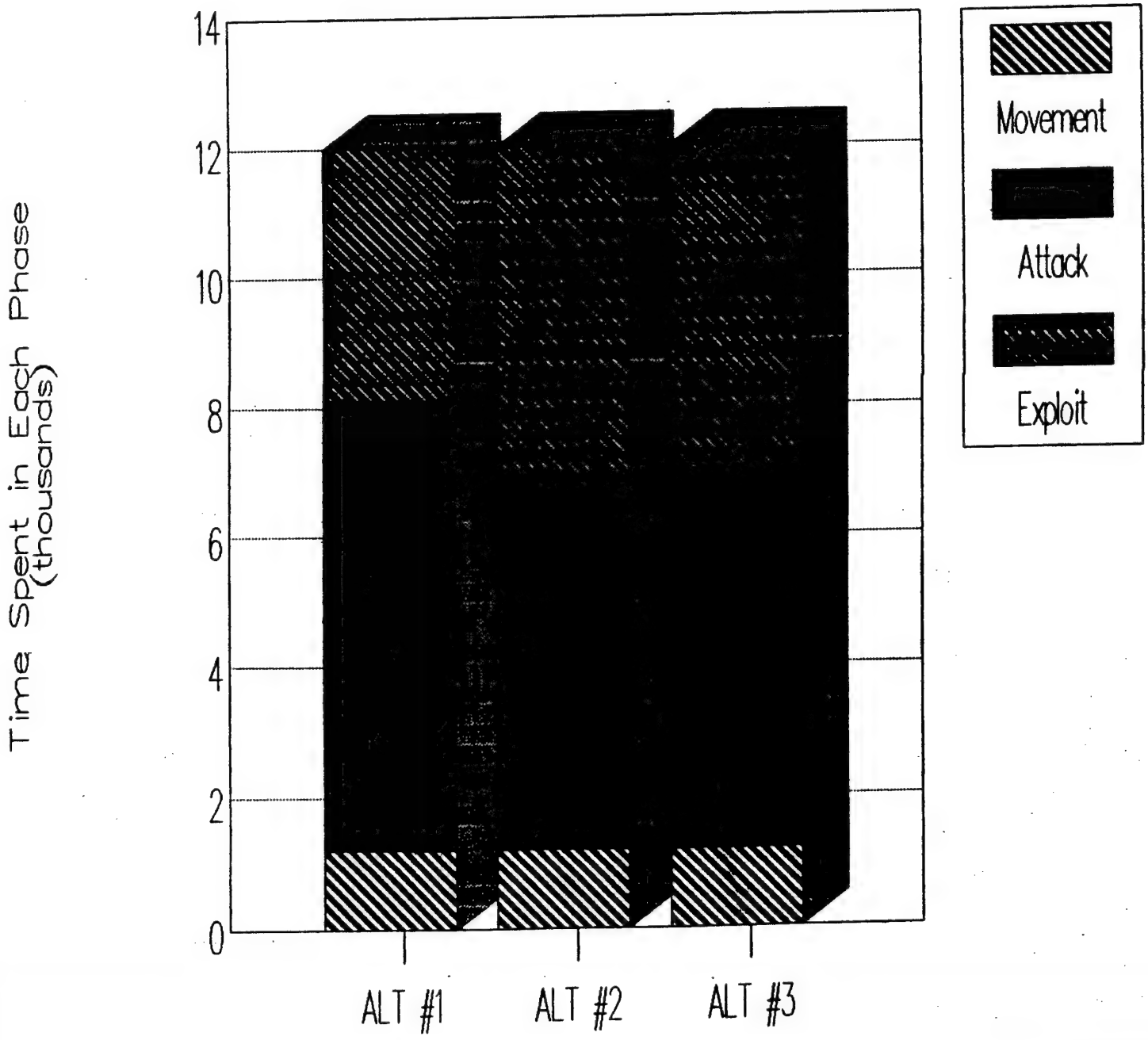
Eagle C2

MOE #3



Eagle C2

MOE #3



ANNEX D: Statistical Analysis - The Quade Test

Why use Non-parametric statistics with output from the Eagle combat simulation?

The Eagle model does not use stochastic techniques to simulate the variabilities of combat. Rather, it uses deterministic methods. Therefore, any one set of input parameters always results in an identical set of output results. Eagle is based on expected values and this eliminates the need for averaging multiple runs, which can be extremely time-consuming. The model is not based on any distribution function, so non-parametric techniques must be used to analyze any data from Eagle (Cononver, 92).

The Quade Test (Conover, 295-297)

The data used to evaluate each MOE was organized into a 3x3 matrix where the rows represented the phass of the attack and the columns represented the alternative units. The alternatives are considered the treatments and the phases are the blocks. The result was a randomized complete block design, and the Quade Test was an easy and effective method to evaluate the data.

1) The data within each block are ranked. One is given to the smallest value and tied values are given the average of their ranks. Each value is designated as R(Xij), where i is the treatment number and j is the block number.

2) The range within each block is calculated and ranked in a similar manner. These values are designates as Qi.

3) The value $Sij = Qi*(R(Xij)-(K+1)/2)^{(1/2)}$ is computed for each value. K is the number of treatments.

4) Sj = SUM(Sij) is computed for each treatment, where b is the number of blocks.

5) The hypothesis test:

"Ho: Each ranking of the random variables within a block is equally likely.

"H1: At least one of the treatments tends to yield larger observed values than at least one other treatment." (297)

6) Test Statistic

$A1 = SUM\ Sij^2$

$B1 = (SUM\ Sj)/b$

$T1 = ((b-1)*B1)/(A1-B1)$

7) Decision: if $T1 > F1-a,k-1,(b-1)(k-1)$ then reject Ho

8) If Ho is rejected, conduct tests on each individual pair of treatments.

$$|Si-Sj| > t1-a/2*((2*b*(A1-B1))/((b-1)*(a-1))^(1/2)$$

If this inequality holds true then the treatments i and j are considered different.

Annex E

MOE Definition Format
Used for C2 MOE under Eagle

Title	Description
Definition of the Measure	- Statement which includes data and processing methods
Dimension of the Measure	- How the MOE is expressed: as percentage, rank, quotient
Limits on the Range of Measure	- Input or output limits of MOE
Rationale for the Measure	- Properties which make MOE useful for analysis
Relevance of the Measure	- Contribution to the decision making process
Associated MOE	- Other MOE which enhance or may substitute one used
References	- Studies, tests and manuals which used or discussed MOE.

TRAC-OAC Rsch by CPT G. Stone

ANNEX F

MEASURES OF EFFECTIVENESS

PART I: Combat Development Functions

- Doctrine
- Organization
- Material
- Training
- Logistics

PART II: Land Combat Functions

- Command-Control-Communications
- Firepower
- Mobility
- Intelligence
- Combat Service Support

(from Force Developments: The Measures of Effectiveness)

ANNEX G

MEASURES OF EFFECTIVENESS

COMMAND AND CONTROL

- Repetitions per Order
- Changes per Order
- Percent planning time forwarded
- Proportion friendly elements engaged
- Mean dissemination time
- Percent actions initiated by time ordered

(from Force Developments: The Measures of Effectiveness)

ALTERNATIVE #11 Brigade Baseline

ANNEX H

	Unit	Time(sec)	Day	Clk Time	Speed(kmh)
Movement to Passage	2	21600	0	600	0
	2	21900	0	605	2.4
	2	22200	0	610	0
	2	22500	0	615	12.8
	2	22800	0	620	0.97
		1200		20	3.234
Attack at FEBA	2	23100	0	625	12.6
	2	23400	0	630	12.3
	2	23700	0	635	12.2
	2	24000	0	640	12.2
	2	24300	0	645	10.9
	2	24600	0	650	12.1
	2	24900	0	655	11.9
	2	25200	0	700	11.8
	2	25500	0	705	12.2
	2	25800	0	710	3.48
	2	26100	0	715	3.48
	2	26400	0	720	4.48
	2	26700	0	725	2
	2	27000	0	730	2
	2	27300	0	735	2
	2	27600	0	740	2
	2	27900	0	745	1
	2	28200	0	750	1
	2	28500	0	755	2
	2	28800	0	800	4
	2	29100	0	805	4
	2	29400	0	810	4
	2	29700	0	815	7.25
	2	30000	0	820	0
		6900		195	6.2870833
Exploitation	2	30300	0	825	16
	2	30600	0	830	14.1
	2	30900	0	835	14.3
	2	31200	0	840	12.5
	2	31500	0	845	14.2
	2	31800	0	850	3.67
	2	32100	0	855	0.83
	2	32400	0	900	5.85
	2	32700	0	905	2
	2	33000	0	910	2
	2	33300	0	915	2
	2	33600	0	920	2
	2	33900	0	925	4
	2	34200	0	930	4
		3900		105	6.9607143

# Vehs	% Eff	#Decision by Suhord	#Decision by CMD	By Phase Cumulative Decisions
191	100	18	5	23
191	100	7	0	30
191	100	12	1	43
191	100	4	1	48
191	100	10	2	60
191	100	10.2	1.8	60
191	100	5	1	6
191	100	0	0	6
191	100	0	0	6
191	100	0	0	6
191	100	0	0	6
191	100	0	0	6
191	100	0	0	6
191	100	0	0	6
191	100	1	0	7
189	99	4	1	12
188	98	6	4	22
186	98	7	1	30
181	95	2	1	33
176	93	2	0	35
172	91	2	2	39
169	90	1	1	41
164	87	4	0	45
160	85	4	0	49
160	85	0	0	49
159	84	1	0	50
159	84	3	1	54
159	84	4	1	59
158	84	5	0	64
158	84	6	2	72
177.375	93.375	2.375	0.625	72
158	84	9	1	10
158	84	4	0	14
158	84	5	0	19
158	84	3	0	22
158	84	3	0	25
156	83	6	0	31
154	82	7	3	41
148	79	5	1	47
141	75	7	0	54
138	74	3	1	58
134	72	2	0	60
132	70	2	0	62
131	70	1	1	64
130	69	1	0	65
146.7143	78.14286	4.1428571	0.5	65

ERNATIVE #2: Brigade Alternative

	Unit	Time(sec)	Day	Clk Time	Speed(kmh)
Movement to Passage	2	21600	0	600	0
	2	21900	0	605	2.4
	2	22200	0	610	0
	2	22500	0	615	12.7
	2	22800	0	620	12.7
		1200		20	5.56
Attack at FEBA	2	23100	0	625	12.6
	2	23400	0	630	12.3
	2	23700	0	635	12.2
	2	24000	0	640	12.1
	2	24300	0	645	12.1
	2	24600	0	650	12.1
	2	24900	0	655	11.9
	2	25200	0	700	12.3
	2	25500	0	705	12.2
	2	25800	0	710	6.97
	2	26100	0	715	3.74
	2	26400	0	720	2
	2	26700	0	725	4
	2	27000	0	730	4
	2	27300	0	735	2
	2	27600	0	740	2
	2	27900	0	745	2
	2	28200	0	750	2
	2	28500	0	755	4
	2	28800	0	800	0
		5700		175	7.1255
Exploitation	2	29100	0	805	0
	2	29400	0	810	7.47
	2	29700	0	815	6.96
	2	30000	0	820	6.96
	2	30300	0	825	6.96
	2	30600	0	830	6.96
	2	30900	0	835	21.8
	2	31200	0	840	17.3
	2	31500	0	845	17.5
	2	31800	0	850	6.2
	2	32100	0	855	0
	2	32400	0	900	0
	2	32700	0	905	0
	2	33000	0	910	0
	2	33300	0	915	0
	2	33600	0	920	0
	2	33900	0	925	0
	2	34200	0	930	0
		5100		125	5.4505556

# Vehs	% Eff	#Decision by Suborn	#Decision by CMD	By Phase Cumulative Decisions
191	100	18	5	23
191	100	7	0	30
191	100	12	1	43
191	100	4	1	48
191	100	12	2	62
191	100	10.6	1.8	62
191	100	6	1	7
191	100	1	0	8
191	100	1	0	9
191	100	2	0	11
191	100	1	0	12
191	100	2	0	14
191	100	1	0	15
191	100	2	0	17
191	100	6	1	24
191	100	10	4	38
190	100	8	1	47
190	100	5	2	54
190	100	2	1	57
190	100	4	0	61
190	100	5	0	66
190	100	3	1	70
189	100	1	0	71
189	99	3	0	74
189	99	3	0	77
189	99	6	2	85
189	99	3.6	0.65	85
189	99	10	1	11
189	99	4	0	15
189	99	4	0	19
189	99	3	0	22
189	99	10	0	32
189	99	3	0	35
189	99	1	0	36
189	99	0	0	36
189	99	1	0	37
189	99	2	0	39
188	99	1	1	41
188	98	0	0	41
188	98	0	0	41
188	98	0	0	41
187	98	0	0	41
187	98	0	0	41
187	98	0	0	41
187	98	0	0	41
187	98	2.1666667	0.1111111	41

ERNATIVE #3: Brigade Alternative with Close Air Support (CAS)

	Unit	Time(sec)	Day	Clk Time	Speed(kmh)
Movement to Passage	2	21600	0	600	0
	2	21900	0	605	2.4
	2	22200	0	610	0
	2	22500	0	615	12.7
	2	22800	0	620	12.7
		1200		20	5.56
Attack at FEBA	2	23100	0	625	12.6
	2	23400	0	630	12.3
	2	23700	0	635	12.2
	2	24000	0	640	12.1
	2	24300	0	645	12.1
	2	24600	0	650	12.1
	2	24900	0	655	11.9
	2	25200	0	700	12.3
	2	25500	0	705	12.2
	2	25800	0	710	6.97
	2	26100	0	715	3.74
	2	26400	0	720	2
	2	26700	0	725	4
	2	27000	0	730	2
	2	27300	0	735	2
	2	27600	0	740	2
	2	27900	0	745	2
	2	28200	0	750	4
	2	28500	0	755	4
	2	28800	0	800	0
		5700		175	7.1255
Exploitation	2	29100	0	805	0
	2	29400	0	810	7.47
	2	29700	0	815	6.96
	2	30000	0	820	6.96
	2	30300	0	825	6.96
	2	30600	0	830	6.96
	2	30900	0	835	6.96
	2	31200	0	840	17.6
	2	31500	0	845	21.8
	2	31800	0	850	6.71
	2	32100	0	855	6.54
	2	32400	0	900	3.27
	2	32700	0	905	0
	2	33000	0	910	0
	2	33300	0	915	0
	2	33600	0	920	0
	2	33900	0	925	0
	2	34200	0	930	0
		5100		125	5.455

# Vehs	% Eff	#Decision by Subord	#Decision by CMU	By Phase Cumulative Decisions
191	100	18	5	23
191	100	7	0	30
191	100	12	1	43
191	100	4	1	48
191	100	12	2	62
191	100	10.6	1.8	62
191	100	6	1	7
191	100	1	0	8
191	100	1	0	9
191	100	2	0	11
191	100	1	0	12
191	100	2	0	14
191	100	1	0	15
191	100	2	0	17
191	100	6	1	24
191	100	10	4	38
190	100	8	1	47
190	100	5	2	54
190	100	3	1	58
190	100	3	1	62
188	98	2	0	64
186	98	5	0	69
186	98	2	1	72
186	98	6	0	78
186	98	4	0	82
186	98	7	2	91
186	98	3.85	0.7	91
186	98	9	1	10
186	98	4	0	14
186	98	4	0	18
186	98	3	0	21
186	98	10	0	31
186	98	6	0	37
186	98	3	0	40
186	98	2	0	42
186	98	1	0	43
186	98	2	0	45
186	97	0	0	45
186	97	2	0	47
185	97	2	1	50
185	97	0	0	50
185	97	0	0	50
185	97	0	0	50
184	97	0	0	50
184	97	0	0	50
184	97	2.6666667	0.1111111	50

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ANNEX H

	Unit	Time(sec)	Day	Clk Time	Speed(km/h)
Movement to Passage	2	21600	0	600	0
	2	21900	0	605	2.4
	2	22200	0	610	0
	2	22500	0	615	12.8
	2	22800	0	620	0.97
		1200		20	3.234
Attack at FEBA	2	23100	0	625	12.6
	2	23400	0	630	12.3
	2	23700	0	635	12.2
	2	24000	0	640	12.2
	2	24300	0	645	10.9
	2	24600	0	650	12.1
	2	24900	0	655	11.9
	2	25200	0	700	11.8
	2	25500	0	705	12.2
	2	25800	0	710	3.48
	2	26100	0	715	3.48
	2	26400	0	720	4.48
	2	26700	0	725	2
	2	27000	0	730	2
	2	27300	0	735	2
	2	27600	0	740	2
	2	27900	0	745	1
	2	28200	0	750	1
	2	28500	0	755	2
	2	28800	0	800	4
	2	29100	0	805	4
	2	29400	0	810	4
	2	29700	0	815	7.25
	2	30000	0	820	0
		6900		195	6.2870833
Exploitation	2	30300	0	825	16
	2	30600	0	830	14.1
	2	30900	0	835	14.3
	2	31200	0	840	12.5
	2	31500	0	845	14.2
	2	31800	0	850	3.67
	2	32100	0	855	0.83
	2	32400	0	900	5.85
	2	32700	0	905	2
	2	33000	0	910	2
	2	33300	0	915	2
	2	33600	0	920	2
	2	33900	0	925	4
	2	34200	0	930	4
		3900		105	6.9607143

# Vehs	% Eff	#Decision by Sunora	#Decision by CMD	By Phase Cumulative Decisions
191	100	18	5	23
191	100	7	0	30
191	100	12	1	43
191	100	4	1	48
191	100	10	2	60
191	100	10.2	1.8	60
191	100	5	1	6
191	100	0	0	6
191	100	0	0	6
191	100	0	0	6
191	100	0	0	6
191	100	0	0	6
191	100	0	0	6
191	100	0	0	6
191	100	1	0	7
189	99	4	1	12
188	98	6	4	22
186	98	7	1	30
181	95	2	1	33
176	93	2	0	35
172	91	2	2	39
169	90	1	1	41
164	87	4	0	45
160	85	4	0	49
160	85	0	0	49
159	84	1	0	50
159	84	3	1	54
159	84	4	1	59
158	84	5	0	64
158	84	6	2	72
177.375	93.375	2.375	0.625	72
158	84	9	1	10
158	84	4	0	14
158	84	5	0	19
158	84	3	0	22
158	84	3	0	25
156	83	6	0	31
154	82	7	3	41
148	79	5	1	47
141	75	7	0	54
138	74	3	1	58
134	72	2	0	60
132	70	2	0	62
131	70	1	1	64
130	69	1	0	65
146.7143	78.14286	4.1428571	0.5	65

ERNATIVE #2: Brigade Alternative

	Unit	Time(sec)	Day	Clk Time	Speed(kmh)
Movement to Passage	2	21600	0	600	0
	2	21900	0	605	2.4
	2	22200	0	610	0
	2	22500	0	615	12.7
	2	22800	0	620	12.7
		1200		20	5.56
Attack at FEBA	2	23100	0	625	12.6
	2	23400	0	630	12.3
	2	23700	0	635	12.2
	2	24000	0	640	12.1
	2	24300	0	645	12.1
	2	24600	0	650	12.1
	2	24900	0	655	11.9
	2	25200	0	700	12.3
	2	25500	0	705	12.2
	2	25800	0	710	6.97
	2	26100	0	715	3.74
	2	26400	0	720	2
	2	26700	0	725	4
	2	27000	0	730	4
	2	27300	0	735	2
	2	27600	0	740	2
	2	27900	0	745	2
	2	28200	0	750	2
	2	28500	0	755	4
	2	28800	0	800	0
		5700		175	7.1255
Exploitation	2	29100	0	805	0
	2	29400	0	810	7.47
	2	29700	0	815	6.96
	2	30000	0	820	6.96
	2	30300	0	825	6.96
	2	30600	0	830	6.96
	2	30900	0	835	21.8
	2	31200	0	840	17.3
	2	31500	0	845	17.5
	2	31800	0	850	6.2
	2	32100	0	855	0
	2	32400	0	900	0
	2	32700	0	905	0
	2	33000	0	910	0
	2	33300	0	915	0
	2	33600	0	920	0
	2	33900	0	925	0
	2	34200	0	930	0
		5100		125	5.4505556

# Vehs	% Eff	#Decision by Suborn	#Decision by CMD	By Phase Cumulative Decisions
191	100	18	5	23
191	100	7	0	30
191	100	12	1	43
191	100	4	1	48
191	100	12	2	62
191	100	10.6	1.8	62
191	100	6	1	7
191	100	1	0	8
191	100	1	0	9
191	100	2	0	11
191	100	1	0	12
191	100	2	0	14
191	100	1	0	15
191	100	2	0	17
191	100	6	1	24
191	100	10	4	38
190	100	8	1	47
190	100	5	2	54
190	100	2	1	57
190	100	4	0	61
190	100	5	0	66
190	100	3	1	70
189	100	1	0	71
189	99	3	0	74
189	99	3	0	77
189	99	6	2	85
189	99	3.6	0.65	85
189	99	10	1	11
189	99	4	0	15
189	99	4	0	19
189	99	3	0	22
189	99	10	0	32
189	99	3	0	35
189	99	1	0	36
189	99	0	0	36
189	99	1	0	37
189	99	2	0	39
188	99	1	1	41
188	98	0	0	41
188	98	0	0	41
188	98	0	0	41
187	98	0	0	41
187	98	0	0	41
187	98	0	0	41
187	98	0	0	41
187	98	2.1666667	0.1111111	41

ERNATIVE #3: Brigade Alternative with Close Air Support (CAS)

	Unit	Time(sec)	Day	Clk Time	Speed(kmh)
Movement to Passage	2	21600	0	600	0
	2	21900	0	605	2.4
	2	22200	0	610	0
	2	22500	0	615	12.7
	2	22800	0	620	12.7
		1200		20	5.56
Attack at FEBA	2	23100	0	625	12.6
	2	23400	0	630	12.3
	2	23700	0	635	12.2
	2	24000	0	640	12.1
	2	24300	0	645	12.1
	2	24600	0	650	12.1
	2	24900	0	655	11.9
	2	25200	0	700	12.3
	2	25500	0	705	12.2
	2	25800	0	710	6.97
	2	26100	0	715	3.74
	2	26400	0	720	2
	2	26700	0	725	4
	2	27000	0	730	2
	2	27300	0	735	2
	2	27600	0	740	2
	2	27900	0	745	2
	2	28200	0	750	4
	2	28500	0	755	4
	2	28800	0	800	0
		5700		175	7.1255
Exploitation	2	29100	0	805	0
	2	29400	0	810	7.47
	2	29700	0	815	6.96
	2	30000	0	820	6.96
	2	30300	0	825	6.96
	2	30600	0	830	6.96
	2	30900	0	835	6.96
	2	31200	0	840	17.6
	2	31500	0	845	21.8
	2	31800	0	850	6.71
	2	32100	0	855	6.54
	2	32400	0	900	3.27
	2	32700	0	905	0
	2	33000	0	910	0
	2	33300	0	915	0
	2	33600	0	920	0
	2	33900	0	925	0
	2	34200	0	930	0
		5100		125	5.455

# Vehs	% Eff	#Decision by Subord	#Decision by CMU	By Phase Cumulative Decisions
191	100	18	5	23
191	100	7	0	30
191	100	12	1	43
191	100	4	1	48
191	100	12	2	62
191	100	10.6	1.8	62
191	100	6	1	7
191	100	1	0	8
191	100	1	0	9
191	100	2	0	11
191	100	1	0	12
191	100	2	0	14
191	100	1	0	15
191	100	2	0	17
191	100	6	1	24
191	100	10	4	38
190	100	8	1	47
190	100	5	2	54
190	100	3	1	58
190	100	3	1	62
188	98	2	0	64
186	98	5	0	69
186	98	2	1	72
186	98	6	0	78
186	98	4	0	82
186	98	7	2	91
186	98	3.85	0.7	91
186	98	9	1	10
186	98	4	0	14
186	98	4	0	18
186	98	3	0	21
186	98	10	0	31
186	98	6	0	37
186	98	3	0	40
186	98	2	0	42
186	98	1	0	43
186	98	2	0	45
186	97	0	0	45
186	97	2	0	47
185	97	2	1	50
185	97	0	0	50
185	97	0	0	50
185	97	0	0	50
184	97	0	0	50
184	97	0	0	50
184	97	2.6666667	0.1111111	50